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FUME AND OTHER LOSSES IN CONDENSING QUICKSILVER FROM FURNACE GASES

BY

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FUME AND OTHER LOSSES IN CONDENSING QUICKSILVER FROM FURNACE GASES.

By L. H. Duschak and C. N. Schuette.

INTRODUCTION.

The work covered by this report was conducted by the Federal Bureau of Mines, through its experiment station at Berkeley, Cal., in cooperation with the New Idria Quicksilver Mining Co. and the Oceanic quicksilver mine. Part of the expense was borne by these concerns and their liberality in placing their plant facilities at the disposal of the Bureau of Mines has greatly assisted the work.

The authors thank Mr. H. W. Gould, general superintendent of the New Idria Quicksilver Mining Co., and Mr. Murray Innes, owner and manager of the Oceanic quicksilver mine, and the officers of these companies for the many courtesies extended. Mr. Clifford G. Dennis, president and manager of the St. Johns Mines Co., has also assisted by counsel freely given.

Acknowledgment is made of the assistance of the following members of the Bureau of Mines: G. N. Libby and Vance P. Edwardes, in the field work; and Messrs. W. C. Riddell and C. M. Bouton, for the analytical work.

The magnitude of the metal losses incident to the condensation of mercury from furnace gases has been a much-discussed question among quicksilver operators, but aside from the work of Christy[a] at New Almaden, Cal., in 1885 no study of the subject has been reported in this country. An elaborate examination of this question at the Imperial Quicksilver Works at Idria (Krain, Austria) has been made by Cástek.[b] No satisfactory application of his conclusions, however, can be made to American practice, because of the many ways in which this differs from European practice. Metal losses, amounting to 30 to 40 per cent of the plant input, have been suspected at some plants. Unfortunately the conspicuous lack of technical control at quicksilver reducing plants has usually rendered impossible the placing of even an upper limit for condenser losses by calculating the gross loss incident to the entire process of ore treatment.

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[a] Christy, S. B., Quicksilver condensation at New Almaden, Cal.: Trans. Am. Inst. Min. Eng., vol. 14, 1885, p. 206.

[b] Cástek, Franz, Die Bestimmung und Verminderung der Verluste beim Quecksilberhütten: Berg- und Hüttenm. Jahrb., Bd. 58, 1910, pp. 1 and 231.

The investigation described herein was undertaken with a view to making direct quantitative determinations of these losses.

REDUCTION WORKS INVESTIGATED.

NEW IDRIA QUICKSILVER MINING CO.

As more than two-thirds of the plant output of the New Idria company is derived from the No. 1 furnace, this was selected for study. It is a Hüttner-Scott furnace (now commonly known as the Scott furnace), with a rated capacity of 60 tons daily. In May, 1918, about 70 tons of fine ore and concentrate, making a charge averaging about 1.25 per cent mercury, was being treated in 24 hours.

Fuel oil of 18° B. gravity is used as fuel, there being two burners in the main fire box and one burner in the lower (rear) dust or vapor chamber. The fuel consumption per 24 hours is about 450 gallons, or 2.6 per cent by weight of the charge.

What is herein designated as the "old" condenser system comprised the customary series of brick and stone chambers followed by eight wooden barrels, then a blower, and a side-hill flue leading to the stack.

Before the second series of condenser-loss determinations was made, a "new" system was constructed, which retains only the first brick condenser of the "old" system. This condenser is followed by a line of tile pipe, then three large wooden tanks in series connected with wooden flues, followed by the eight wooden barrels, fan, flue, and stack of the former system.

The fume cloud leaving the stack with the "new" system is shown in Plate I, *A*.

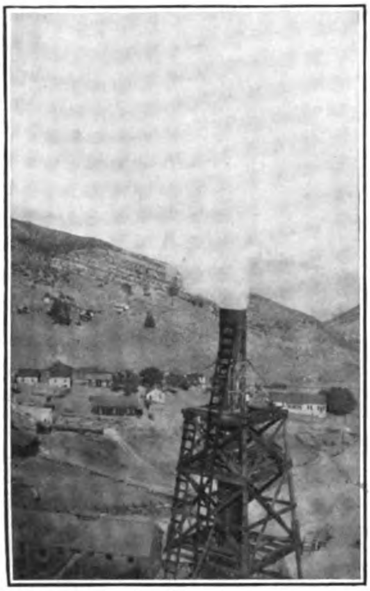
OCEANIC QUICKSILVER MINING COMPANY.

Two Scott furnaces, with a rated capacity of 50 tons each, are in use at the Oceanic plant. About 90 tons of ore, carrying 0.25 to 0.3 per cent mercury, is treated in 24 hours.

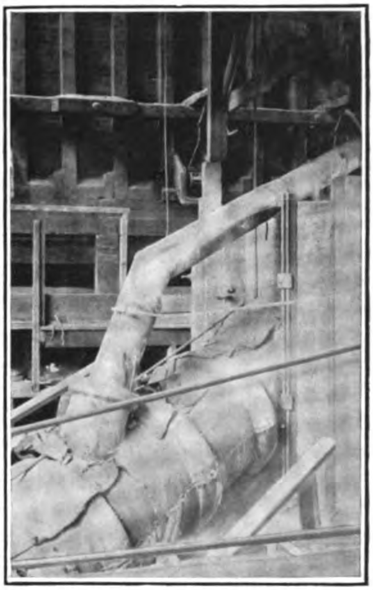
Wood fuel is used in the main fire box only, there being no booster fire in the rear chamber. The total fuel consumption is 2 to 2.5 cords a day, or, roughly, 3 per cent by weight of the furnace charge.

Back of each furnace is a brick condenser, then a series of brick and wooden chambers, which combine into a common system leading to a side-hill flue and stack.

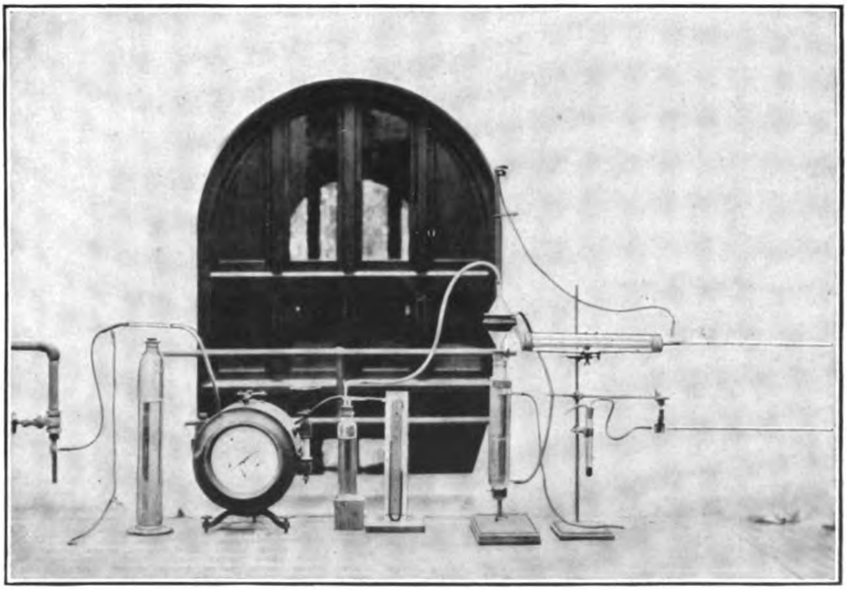
The condenser systems of both the Oceanic and the New Idria plants are described in detail in another part of this paper.



A. FUME CLOUD LEAVING STACK, NEW SYSTEM.



B. CONDENSER AND TILE PIPE, OLD SYSTEM, AT NEW IDRIA.



C. FUME-SAMPLING APPARATUS.

LOSSES IN CONDENSING QUICKSILVER.

A preliminary survey showed that the usual methods of fume sampling employed at lead and copper smelters could not be used without considerable modification, because of the large amount of water mist present in the stack gases. The method here described was developed and first used at the New Idria plant in May, 1917.

APPARATUS.

The apparatus used is shown in Plate I, *C*, and in figure 1. The gas passed successively through a glass sampling tube, a short Liebig condenser, a water-cooled bead tower, a Hawley filter,[a] and a wash bottle, and then through a small gas meter to a water jet pump which provided the necessary suction.

The sampling tube was of glass, about 4 mm. (0.15 inch) in inner diameter, closed at one end but having, close to that end, an opening blown in the side. This tube was placed with the opening near the middle of the gas stream and facing the direction of flow.

The bead tower which followed the Liebig condenser was of glass about 25 mm. (1 inch) in inner diameter, and 300 mm. (12 inches) long. The upper two-thirds was filled with solid glass beads supported on a perforated porcelain plate. It is important that this plate be notched at the edges so that liquid collecting on the beads will not be prevented, by the ascending gas stream, from draining into the reservoir below. Both the Liebig condenser and the water jacket to the bead tower were cooled with ice water or cold tap water.

The Hawley filter was arranged in the usual way with accurately ground funnels about 90 mm. (3.5 inch) in diameter. Soft, rather thick, filter paper was used. A section of the inner tube of a small automobile tire, placed with the smooth surface next to the glass, gave a firm and air-tight joint.

The wash bottle was charged with sodium-hydroxide solution to remove SO_2 before the gas passed to the meter. Considerable CO_2 was no doubt absorbed also. A vertical water manometer interposed between the wash bottle and the gas meter indicated the reduction in pressure below atmospheric at which the meter worked. The gas meter was a standard laboratory instrument made by the American Meter Co.

In order to insure a steady and easily adjusted suction, a regulating device was placed in the circuit between the gas meter and the aspirator. This device consisted of a tall, glass cylinder with a two-hole stopper; a movable glass tube for admitting air passed through

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[a] Hawley, F. G., Determination of SO_3 in flue gas: Eng. and Min. Jour., vol. 94, 1912, p. 987.

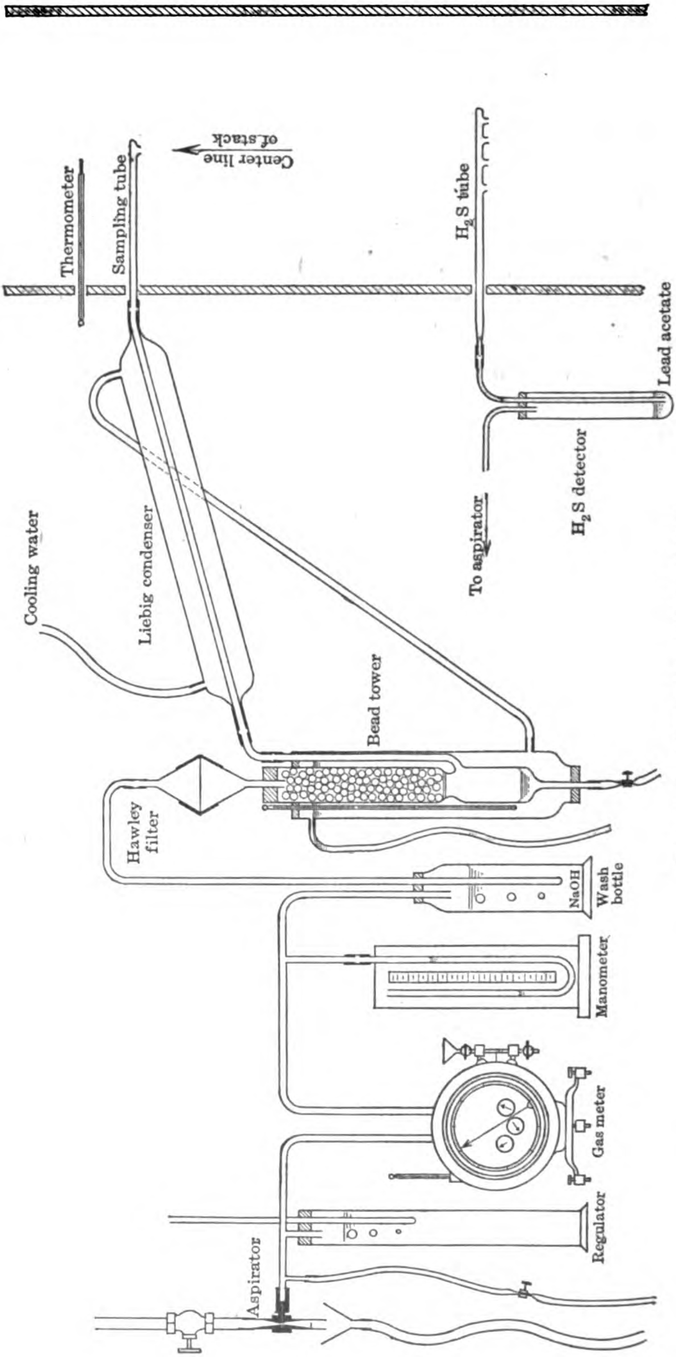

FIGURE 1.—Fume-sampling apparatus.

one hole and the other carried a T-tube through which the meter and the aspirator were connected.

Thermometers were placed in the water jacket of the bead tower, the gas meter, and in the stack carrying the gases under examination.

POINT OF TAKING SAMPLE.

At each plant a sampling point in the flue system was selected beyond which the amount of mercury recovered was negligible. At the New Idria plant samples were drawn from the 35-foot wooden stack, a few feet above its base.

At the Oceanic plant an auxiliary draft flue carrying hot gases from a wood fire enters the main 3-foot flue a short distance from the stack. Samples were therefore taken from the main flue just before the juncture with the auxiliary draft flues.

SAMPLING PROCEDURE.

After the apparatus, except the sampling tube, had been assembled, the aspirator was started and, by closing the intake end of the system, a test was made to ascertain that the system did not leak. Special care in placing the sampling tube in the stack or flue was necessary in order to avoid contamination by the mercury that coated the interior. Error from this source was avoided by wrapping the sampling tube in a strip of paper twisted together at the end. The paper-covered tube was shoved part way into the stack or flue and the sampling tube was then punched through the twisted end. In removing the sampling tube the operation was reversed; the tube was drawn well into the paper cover, then the tube and the paper were withdrawn together. After the sampling tube had been properly connected, the meter was set at zero and the taking of the sample started by closing a by-pass connected to the suction line from the aspirator.

The suction was so regulated that gas was drawn through the apparatus at the rate of approximately 2 liters a minute. At this rate the velocity of the gas entering the sampling tube was roughly that of the gas stream. In spite of the precautions for stopping the water vapor and mist, the filter paper gradually became damp, thus considerably increasing the resistance offered to the passage of gas. The effect of this higher resistance was in a measure offset by increasing the suction which, however, was limited by the inability of the moist filter paper withstanding a pressure of more than 100 to 180 mm. of water. Therefore the rate of sampling decreased gradually, but in view of the low velocity of the flue gases (less than 2 meters a second) and the minuteness of the fume particles in suspension, it seems unlikely that the momentum of any appreciable number of particles was sufficient to cause them to enter the sampling tube except with the gas stream. Difficulty from dampening of the filter paper was least when ice water was used in the condenser and in the jacket of the bead tower.

At intervals during the sampling period the flue gas, meter, and water-jacket temperatures and the meter and water manometer readings were recorded. Also, the barometric pressure was noted, and usually at least one flue-gas velocity determination was made by the method described in a subsequent page. Sample-taking usually continued until several hundred liters of gas had been withdrawn, or until the rate fell off considerably.

The efficiency of the condensing and filtering apparatus in collecting the mercury was tested by placing a second bead tower and Hawley filter just after the first set in one of the tests. The mercury recovered from the two units was as follows: First tower and filter, 0.0199 gram; second tower and filter, 0.0007 gram. Evidently not more than a few per cent of mercury mist in the fume samples escaped recovery.

PREPARATION AND ANALYSIS OF SAMPLE.

At the close of an experiment, the sampling tube, condenser tube, bead tower, and other parts of the apparatus, including the rubber connections, which might have collected any mercury, were carefully washed with nitric acid. Great care was exercised to avoid any "salting" of the sample by mercury-bearing dirt. This precaution was particularly necessary with the sampling tube, which was thoroughly cleaned on the outside before the mercury within was dissolved.

The glass beads were cleaned by stirring them in a beaker with hot dilute nitric acid and subsequently washing them in a funnel. This procedure was repeated at least once.

All nitric acid solutions that might contain mercury were collected and brought nearly to the neutral point with ammonium hydroxide. Hydrogen sulphide was then passed in for some time, the precipitate was collected on a filter, and the filtrate was again treated with hydrogen sulphide to insure complete precipitation. Any mercuric sulphide in the fume sample obviously would not be affected by the nitric acid treatment, but as the solution was not filtered before precipitation with H_2S, this sulphide would be collected with the precipitated sulphide.

This filter paper bearing the mercuric sulphide precipitate and the paper from the Hawley filter constituted the sample; this was analyzed by a method developed for the purpose, which will be described in a subsequent report.

FLUE-GAS VOLUME DETERMINATION.

The low velocity of the flue gases—less than 2 meters a second—rendered the use of a Pitot tube impossible. Attempts were made to determine the velocity by shooting a cloud of colored dust into the gas stream but, presumably because of the large amount of water mist in suspension, the effect at the stack was too slight to be determined with certainty. The problem was successfully solved by injecting 10 to 12 liters of hydrogen sulphide (H_2S) at the lower end of the flue and detecting, by chemical means, its appearance at the end of a measured length of flue.

A large rubber bag with a neck 2 cm. in diameter was placed between two boards, thus forming a sort of bellows with which the entire volume of hydrogen sulphide could be injected within a fraction of a second. The arrangement for detecting the hydrogen sulphide at the second station is shown in the lower right-hand corner of Plate I, *C*, and figure 1 (p. 6). A glass sampling tube with several openings was placed well across the flue and a stream of gas was drawn by the aspirator from this tube through a small gas-washing tube containing 1 or 2 c. c. of lead acetate solution.[a] A fairly concentrated lead acetate solution slightly acidulated with nitric or acetic acid was found to be most sensitive. The timing was with a stop watch.

The observed velocity was assumed to be a maximum corresponding with that of the more rapidly moving central core of the gas stream. The mean velocity was computed by using the factor 0.9 based on Loeb's experiments. From the mean velocity so obtained, and the flue diameter, which was 3 feet at each place, the gas volume was computed.

As a check on this method, the gas volume was calculated from the fuel consumption and the carbon dioxide content of the stack gases, which were carefully observed during a 3-day period. This calculation showed a stack-gas volume of 75,800 cubic meters of dry gas at standard conditions per 24 hours. The average derived from three velocity determinations during this period was 72,300 cubic meters. In view of the difficulties involved in determining flue-gas volumes, the agreement is considered satisfactory.

CALCULATION OF RESULTS.

In calculating the stack loss from the results of the fume sampling, the volume of dry gas at standard conditions was used as a basis. The observed volume of the sample, as indicated by the meter, was corrected for the meter temperature and for the partial pressure of the dry gas. This latter is equal to the reading of barometric pressure decreased by the aqueous tension at the meter temperature and by the reduced pressure under which the meter operated, as indicated by the manometer. A further correction, in the sense of increasing the sample volume by about 4 per cent, was necessary because of the carbon dioxide and sulphur dioxide absorbed by the wash bottle preceding the meter.

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[a] Loeb, F., The Pitot tube applied to the measurement of air: Jour. Am. Soc. Naval Eng., November, 1912, vol. 24, p. 1115.

Similar corrections, based on the mean flue temperature, the barometric pressure, and the tension of water vapor were applied to the flue-gas volume.

As the sampling procedure did not completely remove all mercury vapor from the flue gas, a correction based on the vapor tension of mercury at the mean temperature of the Liebig condenser and bead tower must be added to the figure for mercury recovered. The earlier values for the vapor tension of mercury below 100° C., including those of Regnault,[a] which have been used rather generally in metallurgical calculations, are much too high. A careful critique of the more recent vapor-pressure determinations led to the mean values given in Table 5, at the end of this paper.

RESULTS.

A summary of the fume-loss determinations is given in Table 1 following.

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[a] Regnault, Forces élastiques des vapeurs à saturation dans le vide: Mém. Acad. Sci. France, t. 26, 1862, p. 339.

TABLE 1.—*Summary of stack fume-loss determinations.*

NO. 1 FURNACE SYSTEM—NEW IDRIA (OLD).

Date (1917).	Average temperature in flue, °C.	Barometric pressure in stack, mm. of Hg.	Fume sample.		Velocity determinations.			Flue-gas volume.			Hg per cubic meter of dry gas at 0° C. and 760 mm., grams.	Observed Hg loss in 24 hours.	
			Volume dry at 0° C. and 760 mm., liters.	Hg found, grams.	Time[a] noted, seconds.	Mean velocity.[b]		Discharge per minute at stack conditions.		Discharge of dry gas in 24 hours at 0° C. and 760 mm., cubic meters.		Kilograms.	Pounds.
						Meters per second.	Feet per second.	Cubic feet.	Cubic meters.				
May 30	40.0	688.59	95.5	0.0031						49,500 (assumed)	0.0325	1.60	3.53
June 1	41.3	688.59	107.8	.0031							.0288	1.42	3.13
6	40.7	688.59	102.2	.0039							.0382	1.88	4.14
17	39.3	692.78	86.5	.0013							.0150	.74	1.62
18	38.5	691.90	161.0	.0030	64.2	1.19	3.92	1,670	47.3	50,800	.0186	.95	2.09
19	39.9	687.58	167.8	.0056	68.0	1.13	3.70	1,570	44.5	46,600	.0334	1.55	3.42
20	38.9	686.30	157.2	.0019	69.0	1.11	3.65	1,550	44.0	46,200	.0121	.56	1.22
21	37.3	686.82	174.6	.0049	59.8	1.28	4.21	1,790	50.7	53,800	.0281	1.50	3.31
23	39.5	689.10	482.0	.0280	58.6	1.30	4.28	1,820	51.5	54,250	.0581	3.14	6.90
25	39.0	688.34	427.0	.0206	57.0	1.34	4.42	1,875	53.1	56,000	.0482	2.69	5.93
Average	39.44									51,275	.0312	1.60	3.53
Calculated Hg vapor not recovered in sampling at 15° C											.0081	.41	.91
Total											.0393	2.01	4.44

NOS. 1 AND 2 FURNACE SYSTEMS—OCEANIC.

Date (1917).	Average temperature in flue, °C.	Barometric pressure in stack, mm. of Hg.	Volume dry at 0° C. and 760 mm., liters.	Hg found, grams.	Time noted, seconds.	Meters per second.	Feet per second.	Cubic feet.	Cubic meters.	Discharge of dry gas in 24 hours at 0° C. and 760 mm., cubic meters.	Hg per cubic meter of dry gas at 0° C. and 760 mm., grams.	Kilograms.	Pounds.
July 16	31.3	754.00	536.4	0.0280	20.0	1.09	3.60	1,530	43.4	52,800	0.0522	2.74	6.04
17	30.7	752.00	527.5	.0173	20.0	1.09	3.60	1,530	43.4	53,000	.0328	1.74	3.82
18	30.5	754.00	220.0	.0084	19.4	1.12	3.69	1,575	43.6	55,000	.0382	2.10	4.62
20	35.4	754.00	431.2	.0289	20.0	1.09	3.60	1,530	43.4	51,600	.0671	3.46	7.60
Average	31.9									53,100	.0475	2.51	5.52
Calculated Hg vapor not recovered in sampling at 15° C											.0081	.43	.94
Total											.0556	2.94	6.46

[a] Distance over which gas travel was timed was 280 feet at the New Idria and 80 feet at the Oceanic plant.

[b] The mean velocity was assumed to be 0.9 of the velocity observed.

TABLE 1.—*Summary of stack fume-loss determinations*—Continued.

NO. 1 FURNACE SYSTEM—NEW IDRIA (NEW).

Date (1917).	Average temperature in flue, °C.	Barometric pressure in stack, mm. of Hg.	Fume sample.		Velocity determinations.			Flue-gas volume.			Hg per cubic meter of dry gas at 0° C. and 760 mm., grams.	Observed Hg loss in 24 hours.	
			Volume dry at 0° C. and 760 mm., liters.	Hg found, grams.	Time noted, seconds.	Mean velocity.		Discharge per minute at stack conditions.		Discharge of dry gas in 24 hours at 0° C. and 760 mm., cubic meters.		Kilograms.	Pounds.
						Meters per second.	Feet per second.	Cubic feet.	Cubic meters.				
December 9	38.1	(a)	72.8	0.0075						(65,000)	0.1030	6.70	14.70
10	39.0	(a)	95.5	.0097	50.0	1.53	5.04	2,140	60.6	64,000	.1015	6.50	14.30
10	39.0	(a)	59.6	.0055	47.0	1.63	5.35	2,270	64.3	68,200	.0924	6.30	13.85
11	37.7	(a)	87.8	.0056	43.0	1.78	5.85	2,480	70.3	75,000	.0637	4.71	10.48
14	36.4	(a)	94.1	.0081	50.0	1.53	5.04	2,140	60.6	65,250	.0860	5.62	12.36
15	36.7	(a)	114.4	.0244	45.0	1.70	5.59	2,370	67.1	72,250	.2135	15.40	33.80
16	36.5	(a)	87.8	.0048	40.0	1.92	6.30	2,660	75.3	81,400	.0547	4.45	9.76
17	38.5	(a)	87.0	.0136	40.0	1.92	6.30	2,660	75.3	80,100	.1563	12.50	27.50
Average	37.7									72,314	.1088	7.77	17.09
Calculated Hg vapor not recovered in sampling at 10° C.											.0057	.41	.90
Total											.1145	8.18	17.99

[a] Assumed to be 690 mm.

The losses shown are to be taken as minimum rather than maximum, since such analytical and other errors as were present would be negative. The variation in individual results may only in part be charged to experimental error, because the furnace conditions, particularly at New Idria, where concentrate was charged at intervals, were not constant.

By using the values interpolated from the table of vapor tensions (Table 5, p. 26) the total stack loss may be apportioned between vapor and mist losses. A cubic meter of flue gas under flue conditions is taken as the unit for the calculations given in Table 2 following:

TABLE 2.—*Mercury losses in flue gas at New Idria and at Oceanic.*

Item.	New Idria.		Oceanic.
	Old system.	New system.	
Mean temperature, °C	39.4	37.7	31.9
Observed loss per cubic meter of dry gas at standard conditions, grams	0.0393	0.1145	0.0556
Volume of gas at standard conditions corresponding to 1 cubic meter of stack gas, cubic meter	0.734	0.742	0.846
Total loss per cubic meter of stack gas, grams of Hg	0.029	0.085	0.047
Vapor loss, grams of Hg	0.059	0.052	0.034
Mist loss by difference, grams of Hg	....	0.033	0.013
Mist, per cent	....	39	28

According to these calculations the gas leaving the old condenser system at New Idria is only half saturated with mercury vapor. This result may seem somewhat surprising but was presumably due to the large amount of air leaking into the condenser system at various points, and to the slow rate of evaporation of the mercury particles covered with a protecting water film. A similar unsaturated condition, as regards arsenic trioxide in the flue gas from a copper smelter, is noted in Technical Paper 81 of the Bureau of Mines.[a]

It is not at all certain that in the other instances the stack gas was saturated with mercury vapor, although enough metal for this purpose was present.

That the mercurial particles leaving the stack are largely free metal is indicated by the following analysis of sludge from the base of the stack. After separating, by centrifuging, as much free mercury and water as possible, the air-dried residue had the following composition:

Analysis of residue.

	Per cent.
Hg (metallic)	64.3
HgS	5.0
Mineral matter (nonvolatile)	4.2
Moisture, acid, and organic matter (by difference)	26.5
Total	100.0

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[a] Welch, H. V., and Duschak, L. H., The vapor pressure of arsenic trioxide: Tech. Paper 81, Bureau of Mines, 1915, p. 20.

COMPARISON WITH PREVIOUS RESULTS.

Christy,[a] from a careful study of the operation of one of the fine-ore (tierra) furnaces at New Almaden, which received 320.9 kg. of mercury in the form of 1.51 per cent ore per 24 hours, accounted for the metal input as follows:

Distribution of mercury in treating ore at New Almaden, Cal.

	Per cent.
Direct yield	92.71
Residue loss	0.66
Vapor loss	1.73
Mist loss (by difference)	4.90
Total	100.00

Taking his figure for the gas volume leaving the stack at 20° C. as 24,306 cubic meters per 24 hours, the above loss is equivalent to a mercury content of 0.658 gram to the cubic meter. Of this content 0.232 gram is charged to vapor loss through the use of an erroneous value for the vapor tension of mercury at this temperature. The correct value for the vapor loss, based on the vapor pressure data given in Table 5 (p. 26), is 0.0132 gram to the cubic meter. No direct determinations of stack loss were made by Christy, and as the values that he adopted were obtained by difference, it is likely that they include losses occurring in other ways. Inaccuracies in sampling and assaying would also affect his result.

Castek's[b] paper on losses at Idria, Austria, contains a tabulation of stack-loss determinations that indicate an average content of 0.00232 gram of mercury per cubic meter of stack gas. With a gas volume of approximately 177,000 cubic meters (stack conditions 15° C. and 724 mm.) per 24 hours, the daily loss was therefore 411 grams, which was about 0.03 per cent of the daily production. The above figure for the mercury content of the Idria stack gas is much less than the values given in Table 2. Apparently, however, the sampling procedure at Idria, which is briefly described as filtration of the stack gas through a plug of glass wool or asbestos in a glass tube, was designed to stop only the mercury mist.

Castek[b] says that a number of attempts to detect a vapor loss gave uniformly negative results. Apparently the stack gas was far from being saturated with mercury vapor. Castek, however, adopts the erroneous value used by Christy in calculating the vapor loss and thus arrives at a value about 25 times too large.

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[a] Christy, S. B., Quicksilver condensation at New Almaden, Cal.: Trans. Am. Inst. Min. Eng., vol. 14, 1885, pp. 206–265.

[a] Cástek, Franz, Die Bestimmung und Verminderung der Verluste beim Quecksilberhüttenwesen: Berg- und Hüttenm. Jahrb., Bd. 58, 1910, p. 235.

[b] Částek, Franz, work cited, p. 239.

DISCUSSION.

The stack losses that the authors found are very small and represent at the New Idria furnace less than 1 per cent and at the Oceanic

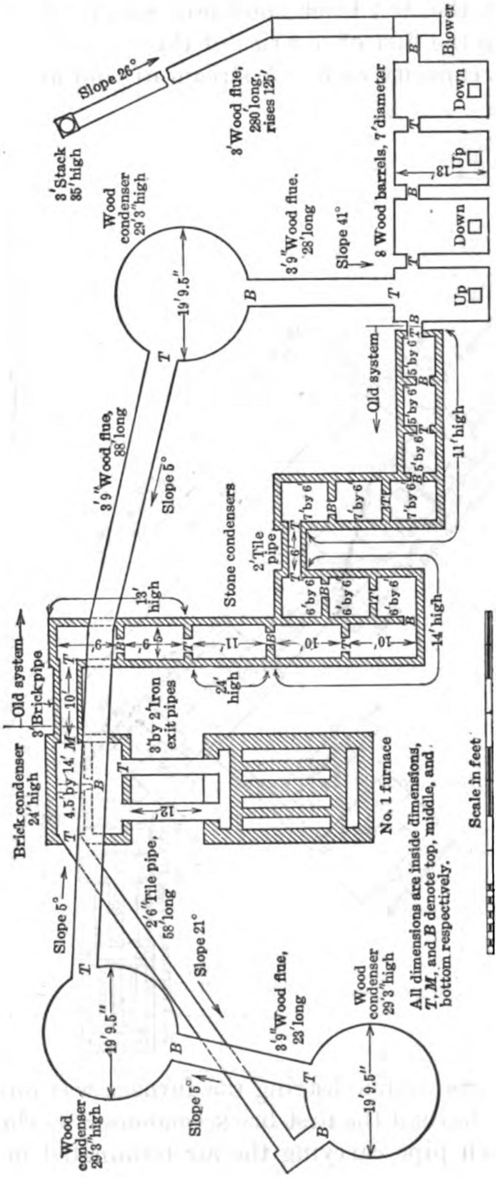

FIGURE 2.—No 1 furnace, with old and new condenser systems, New Idria quicksilver reduction plant.

less than 2 per cent of the mercury input; but it is instructive to determine whether the relative magnitude of these losses is in any way related to the form of condenser system in use. Figure 2 shows the old and new condenser systems of No. 1 furnace at New Idria, and figure 3 the condenser system at Oceanic. The old system at New Idria consisted of the conventional brick and stone chambers, followed by wooden barrels and a sidehill flue and stack. In the new system only the first brick condenser was retained. From this a tile pipe led to the first of a series of three wooden tanks of about 9,000 cubic foot capacity each. A stream of cold air equal to about one-third of the gas volume leaving the furnace was introduced into the tile pipe just beyond the first brick condenser, as shown in Plate I, *B*. The 10-inch pipe carrying the air terminated in a 45° bend, so that the air stream was injected parallel to the center line of the tile pipe. A water spray was introduced with the air.

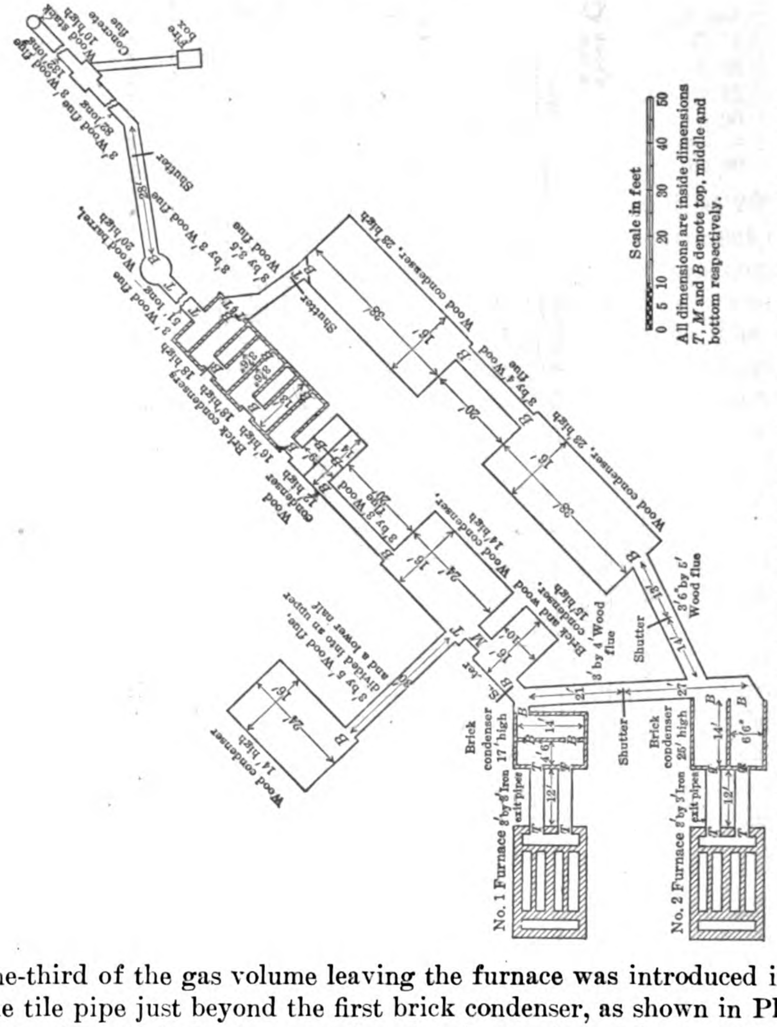

FIGURE 3.—Furnaces and condenser systems, Oceanic quicksilver reduction plant.

The condenser system at Oceanic consists largely of rectangular wooden chambers. Such data pertaining to these condenser systems as may have a bearing on fume losses is assembled in Table 3.

Table 3.—*Data on condenser systems.*

Item.	New Idria.		Oceanic.	
	No. 1, old.	No. 1, new.	No. 1.	No. 2.
Interior volume, cubic meters	489.0	1,098.5	723.9	1,090.0
Interior area, square meters	1,331.8	1,651.5	1,555.2	1,505.9
Materials of construction, percentage of volume inclosed by:				
Iron and tile	1.00	1.20	.80	.60
Brick and stone	63.00	8.20	27.00	16.00
Wood	36.00	90.60	72.20	83.40
Length of gas path, meters	261.0	253.0	165.0	166.0
Changes of direction of gas stream	52	26	25	12
Changes of velocity of gas stream	48	24	30	10
Gas volume, cubic meters at stack conditions:				
Per 24 hours	69,800	97,430	62,800	
Per ton of ore [a]	1,160 (60)	1,400 (70)	700 (90)	
Per kilogram of Hg. [a]	116 (600)	118 (825)	370 (170)	
Mean flue velocity, meters per second	1.37	1.91	1.23	
Mean stack temperature, °C.	39.4	37.7	31.9	
Hg. content per cubic meter of gas, stack conditions, grams	0.029	0.085	0.047	
Loss of Hg. per 24 hours, kilograms	2.01	8.18	2.94	

[a] Figures in parenthesis indicate approximate daily tonnage and daily quicksilver production in kilograms.

As regards the old and the new systems at New Idria, the daily loss from the latter was roughly four times that from the former, although the volume of the new condenser system is more than double that of the old. On the other hand, the factors favoring a larger loss from the new system were a gas volume 50 per cent larger, with a consequently higher mean velocity throughout the condenser system, and fewer changes of velocity and direction in the gas stream. The final stack temperature was essentially the same in both systems.

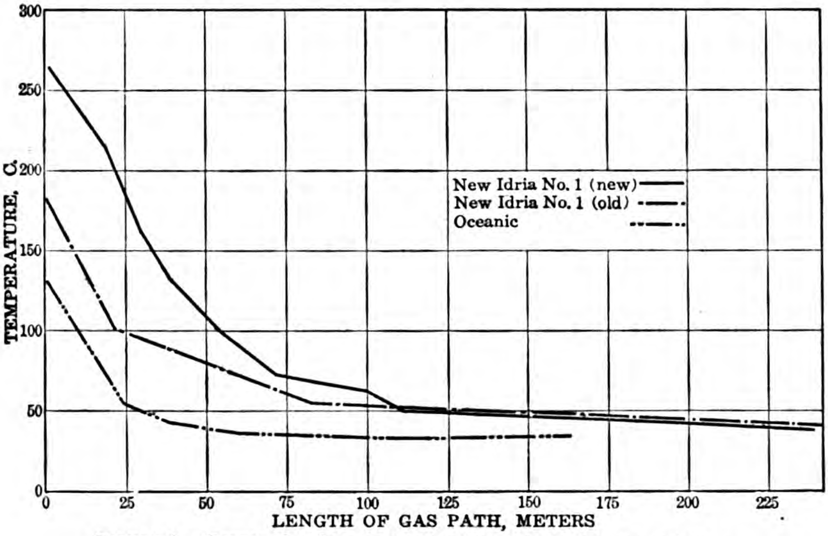

Figure 4.—Curves showing temperature drop in condenser systems.

The temperature drop in the condenser systems at New Idria and Oceanic is shown in figure 4. Comparison of the old system at New Idria with the Oceanic system shows that the equivalent volume of the latter, which is composed of two partly separate systems, is about twice that of the former; also, the mean stack temperature at Oceanic is considerably lower. In spite of these favorable factors the daily mercury loss is a little larger. It is to be noted, however, that the number of changes in velocity and direction of the gas stream is distinctly less at Oceanic.

A permissible conclusion from the data just presented is that the baffling effect in the conventional brick or stone condenser system is considerably more effective in recovering quicksilver than a mere increase in condenser volume.

It is obvious, of course, that the gas volume should be as small as possible. For a given condenser system, other things being constant, an increase in the gas volume will produce more than a proportionate increase in the mist loss alone, because the higher velocity of the gas stream will considerably increase its carrying power. Richards[a] says that the carrying power of the gas stream is probably proportional to the cube of its velocity. The vapor loss, assuming the stack gas to be saturated would be proportional to the volume.

As regards vapor loss, a reduction to 20° C. of the temperature of the gas leaving the new system at New Idria would convert nearly three-fourths of the escaping mercury vapor, equivalent to 3.6 kg. (8 pounds) per 24 hours, into mist which could be recovered if recovery were deemed worth while. A similar reduction in temperature at Oceanic would convert, roughly, three-fifths of the vapor, equivalent to 1.2 kg. (2.6 pounds) per 24 hours, into mist.

The mercury particles in suspension, as has been suggested above, can be partly removed from the gas stream by suitable baffling. An elaborate series of experiments on the separation of suspended particles from the gas stream by different methods of baffling was conducted at the Great Falls plant of the Anaconda Copper Mining Co. several years ago. From consideration of the amount of dust collected, the interference with draft, and other important factors, including the cost of construction, it was concluded that baffles consisting of wires hung vertically a few inches apart were the most effective.[b] In a quicksilver condenser vertical strips of wood might be used instead of wires.

Without doubt, the most effective way of recovering all mercury in suspension would be by electrical precipitation. This method has been employed by the New Almaden Quicksilver Mining Co., in connection with its Herreshoff furnaces, both for removing dust from the hot gases and for recovering mercury mist from the final stack gases.

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[a] Richards, J. W., Metallurgical calculations, pt. 3, 1908, pp. 630–631.

[b] Goodale, C. W., and Klepinger, J. H., The Great Falls flue system and chimney: Trans. Am. Inst. Min. Eng., vol. 46, 1913, p. 583.

The practicability of installing a system for recovering the mercury mist from the stack gases is a question which would require study at each plant. A more detailed consideration of this question and of the general condenser problem is reserved for a later paper.

WATER LOSSES.

Water escaping from a condenser system may carry mercury either in the form of minute metallic particles, commonly called flowered mercury, or in the form of mercury salts in solution. Částek[a] concluded that at Idria the mercury loss in the water leaving the first portion of the condenser system, which was constructed of vitrified stone ware pipes, amounted to about 0.1 per cent of the input or, roughly, 17 kg. a day.

The question of water losses was investigated coincident with the determination of stack loss. With the old condenser system at New Idria (see (fig. 2, p. 17) it was impossible to measure or to sample accurately the water leaving the condenser system, as an unknown amount escaped through the bottom of the brick and stone condensers into the earth. A sample of water taken shortly after a clean-up and probably carrying more than the normal amount of mercury was found to contain 0.15 gram of mercury per liter. In the absence of a direct determination, the maximum amount of water that might escape from the condenser system was calculated by deducting from the total amount leaving the furnace the part escaping from the stack as mist and water vapor. This latter figure was arrived at from some rough observations taken in the course of the fume sampling. On that basis the waste water was found to be something less than 2,000 liters a day. If this is taken as an average value, the corresponding mercury loss is 0.3 kg. (0.66 pound) a day, or 0.05 per cent of the furnace output.

In operating the new condenser system, water was sprayed into the gas stream and also applied at a number of points to the outside of the wooden tanks and pipe connections. This cooling water, with the water condensed from the furnace gases, escaped from the system at two points. The water from the first and second wooden condensers (see fig. 2) flowed through a series of launders to a single wooden settling box and thence to waste; that from the rest of the

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[a] Částek, Franz, Die Bestimmung und Verminderung der Verluste beim Quicksilberhüttenwesen: Berg. und Hüttenm. Jahrb., Bd. 58, 1910, p. 231.

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system passed through a long series of launders and then through several settling boxes. A number of measurements were made of the volume of water leaving each section of the condenser system under varying conditions, and average samples were taken from each water stream at the point where it finally ran to waste. The results of these observations are given in Table 4, following.

TABLE 4.—*Water-loss data, new condenser system, New Idria.*

	Conditions.	First section, tanks 1 and 2.	Second section, tanks 3, etc.
Mercury in solution ....grams per liter..	Normal..............	0.0404	Trace.
Mercury in suspension..............................do....	.....do...............	0.0412	0.0056
Mercury in solution..................................do....	Just after run down..	0.0088	....
Mercury in suspension..............................do....	.....do...............	0.1395	....
Volume of water per 24 hours.........................liters..	Normal..............	26,300	8,770
Do ....do....	Maximum...........	40,900	29,650
Mercury lost per 24 hours..............................kg..	Normal..............	2.14	0.049

The so-called normal loss was thus 2.14 kg. of mercury per 24 hours. To this must be added about 0.5 kg., representing the additional daily loss occasioned by the agitation of the daily run down. This leads to a total loss of 2.64 kg. (5.8 pounds) a day. The corresponding loss for the maximum water volume observed would be about one and one-half times this.

At the Oceanic plant all condenser water went to a single settling tank. A sample of the overflow from this tank was found to contain 0.018 gram of mercury per liter. With an estimated daily flow of 1,500 liters, the mercury loss would be 0.027 kg. (0.06 pound).

The relatively large loss in the new system at New Idria may be attributed primarily to the increased quantity of water which was, roughly, 20 times that in either of the other systems. Under normal conditions about 50 per cent of this loss was due to metal in suspension, and during the period of the run down the mercury escaping was largely in this form. No doubt a considerable proportion of this suspended metal could be recovered in a suitable system of settling tanks.

The mercury in solution was probably present as sulphate resulting from the action of sulphuric acid on the metal. Mercury can be completely precipitated from solution by scrap iron, but if the condenser water contains much acid, the consumption of iron might be out of proportion to the mercury recovered. At New Idria it so happened that the water supplied to the condensers contains alkali enough to neutralize the acid from the furnace so that sometimes the water leaving the condenser system was actually alkaline. Under these conditions the wastage of iron should be small.

OTHER SOURCES OF LOSS.

Although the loss of metal is not susceptible of measurement, certain other ways in which mercury may escape from the condenser system deserve mention.

GAS LEAKAGE.

It is the usual practice both in this country and in Europe to avoid the danger of mercury loss through gas leakage by operating the condenser system under a slightly reduced draft. There can be little question as to the wisdom of this procedure, for a slight escape of mercury-laden gas will result in a vastly greater loss than that occasioned by the inward leakage of a like amount of air. For example, the daily leakage of 2,500 cubic meters of saturated gas, at 100° C., would result in a vapor loss of 8.1 kg. (17.8 pounds), and the actual loss would probably be somewhat greater because of mercury particles in suspension. This volume is less than 5 per cent of the gas flow observed at the Oceanic plant.

As an inward leakage of air amounting to 20 to 50 per cent of the gas stream has been observed at several furnaces, it is evident that a large loss would result from an equal outward leakage. The danger of serious loss is greatest close to the furnace where the temperature is high and the mercury content of the gases large. The pressure at the top of any condensing chamber will be greater than at the bottom, and for the taller parts of the condenser system, particularly those near the furnace, there may be a considerable pressure difference. An inward draft at the bottom does not necessarily mean an inward draft at the top. Moreover, owing to the more vigorous air currents near the top of the condenser system, leaks in that region may not be evident. All parts of a condenser system should be readily accessible for inspection, and inclined draft gages, such as the Ellison gage, may be used at danger points with advantage to indicate whether a safe condition of inward draft is being maintained.

ABSORPTION LOSSES.

Under absorption losses are included those losses arising from the penetration of the condenser material by mercury. As has been pointed out by Castek[a] and others, this loss is most noticeable with a new condenser system and the mercury retained by the condenser material is supposed to be recovered eventually.

However, mercury loss can occur through the use of pervious condenser material in ways that do not appear to have been recognized. One of the authors of this paper has observed that when in the

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[a] Castek, Franz, work cited.

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course of the periodic "clean-ups" the interior of the brick condensing chambers close to the furnace was washed with water a shower of mercury was apt to fall from the outer surface. This was presumably due to the expulsion of mercury contained in the pores of the brickwork by steam arising from the water that penetrated the hot condenser wall. A similar action may take place automatically at certain points through fluctuations in temperature and in moisture content of the furnace gases.

The phenomenon just cited supports the common belief that the brickwork of an old condenser system is pretty well saturated with mercury. When this condition exists a considerable surface, in the aggregate, of mercury may be exposed on the exterior of the condenser system, and where the temperature is high it is not unlikely that considerable evaporation of mercury occurs. The possibilities in this direction are indicated by some calculations made from data presented by Knudsen.[a]

The amount of mercury that should theoretically evaporate in 24 hours from one square meter of mercury surface in vacuum is, roughly, as follows: At 100° C., 10,000 kg.; at 50° C., 480 kg.; and at 30° C., 110 kg. This enormous rate of evaporation has been nearly attained in actual experiments in vacuum but in the presence of other gases the rate would be very much less. Assuming that mercury exposed to air will evaporate at only one-thousandth of the above rate, the amount of metal which may be lost in 24 hours, per square meter of surface exposed, is still considerable. Moreover, the appearance of some of the condenser systems now in use suggests that the aggregate mercury surface exposed may be considerable.

These considerations emphasize the desirability of building condensers of material impervious to mercury vapor.

MECHANICAL LOSSES.

Mechanical losses of mercury may occur through leaks in the bottom of a condenser system and through spattering during "clean-ups." The older practice of building condensers on or close to the ground makes proper inspection practically impossible, and the considerable quantities of mercury that have recently been recovered from the ground below condenser foundations at two plants in California are convincing evidence that this source of loss should not be neglected.

The practice, now favored, of supporting condensers well above ground, with properly inclined concrete floors below, largely eliminates the danger of mechanical loss.

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[a] Knudsen, Martin, Die maximale Verdampfungeschwindigkeit des Quecksilbers; Ann. Physik, Bd. 47, 1915, pp. 697–708.

CONCLUSION.

The condenser losses that can be accurately measured represent at most only a few per cent of the plant output. One should not conclude from this, however, that the over-all efficiency of condensing systems now in use is of the order of 95 per cent. The losses mentioned in the last part of this report have undoubtedly been large at times. The point of fundamental importance established by this investigation is that there are no inherent difficulties that prevent the recovery of at least 96 to 99 per cent of the mercury vapor entering the condenser system.

VAPOR PRESSURE OF MERCURY.

The following average values for the vapor pressure of mercury were prepared by C. M. Bouton after a critical study of several recent investigations.[a] These vapor pressures are all lower than the old accepted values, the difference being greater at the lower temperatures.

TABLE 5.—*Vapor pressures of mercury.*

Temperature.	Vapor pressure.	Mercury vapor per cubic meter.	
		A.[a]	B.[b]
° C.	*Mm. Hg.*	*Kg.*	*Kg.*
0......	0.000184	0.00000216	0.00000216
10......	.000484	.00000549	.00000569
20......	.00121	.0000132	.0000142
30......	.00277	.0000293	.0000325
40......	.00599	.0000614	.0000704
50......	.0127	.000126	.000149
60......	.0254	.000245	.000298
70......	.0486	.000454	.000584
80......	.0896	.000814	.00105
90......	.1597	.00141	.00188
100......	.2756	.00237	.00324
110......	.4635	.00388	.00545
120......	.7529	.00614	.00885
130......	1.198	.00953	.0141
140......	1.860	.0144	.0219
150......	2.829	.0214	.0334
160......	4.217	.0312	.0498
170......	6.171	.0447	.0731
180......	8.872	.0628	.105
190......	12.55	.0869	.150
200......	17.47	.118	.210

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[a] Smith, A., and Menzies, A. W. C., Studies in vapor pressure, IV; a redetermination of the vapor pressures of mercury from 250° to 435°: Jour. Am. Chem. Soc., vol. 32, 1910, pp. 1434–1447. Knudsen, M., Experimentelle Bestimmung des Drucker gessätigter Quecksilberdämpfe bei 0° und höhren Temperaturen: Ann. Physik, Bd. 29, 1909, pp. 179–193. Knudsen, M., Ein absolutes Manometer: Ann. Physik, Bd. 32, 1910, pp. 809–842. Laby, T. H., Recalculation of the vapour pressure of mercury: Phil. Mag., vol. 16, November, 1908, pp. 789–796. Haber, F., and Kerschbaum, F., Messung kleiner Drucke mit einem schwingenden Quarzfaden; Bestimmung der Dampfdrucke von Quecksilber und Jod: Ztschr. Elektrochemie, vol. 20, May 15, 1914, pp. 296–305.

[b] Weight of mercury per cubic meter of saturated vapor measured at the given temperature.

[c] Weight of mercury required to saturate 1 cubic meter of gas (air) measured at 0° C. and raised to the given temperature under constant pressure. These values are particularly useful in calculations such as those involved in this paper.

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